Control system for VHF Active Phased Array Radar

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Abstract:

A pilot 53-MHz 133-element active phased array radar has been developed at National Atmospheric Research Laboratory to validate the technology concepts like out-door installation of solid-state transmit-receive (TR) modules, beam steering, optical fiber network based control, interface and monitoring of the TR modules etc. This system is developed as a precursor R&D activity for the ultimate up-gradation of the existing 1024-element Indian MST radar (located at Gadanki) into a full-fledged active phased array system. In this paper, we present the details of the radar control system and fiber-based control, interface and monitoring of the TR modules.

KeyWords: TR Modules, optical control network, digital receiver

I INTRODUCTION

The Indian mesosphere-stratosphere-troposphere (MST) Radar [1], located at National Atmospheric Research Laboratory (NARL), is being operated for atmospheric research applications for two decades. The 53-MHz, 1024-element 32x32 array is energized by a peak power of 2.5 MW that is provided by 32 tube-based transmitters whose output varies from 120 kW down to 15 kW. The major challenge with the existing transmitter units is the degradation due to aging. Further, critical high power spare parts are getting obsolete making it difficult to sustain the radar operation. To sustain the radar operations for a long run, an R&D project was taken up to upgrade the Indian MST radar in to a fully active phased array system using the solid-state transmit-receive (TR) modules.

A pilot 53-MHz 133-element active phased array radar has been developed and installed as a precursor project with an objective to validate the technology concepts like out-door installation of solid-state transmit-receive (TR) modules, beam steering, optical interface and control, fiber-based phase calibration etc. Proper control and monitoring of the subsystems in general and TR modules in particular is essential for the normal performance of the radar. An optical Ethernet/distribution network is employed between the indoor radar controller and the out-door TR modules to control, interface with and monitor the TR modules. The network is implemented using optical Ethernet switches and multi-core optical fiber lines to protect the control & communication network from the lightning and thunderstorms. The system has been successfully commissioned and being operated regularly. The system has survived the unprecedented lightning/thunderstorms occurred at NARL owing to the optical network. The details of the radar control configuration are presented in section II and the conclusions are given section III.

II SYSTEM CONTROL CONFIGURATION

The 133-element array is configured with seven segments, each comprising a 19-element hexagonal sub-array employing equilateral triangle grid with an inter-element spacing of 0.7λ, which is 4m. Each element of the array is directly fed by dedicated 1-kW solid-state TR module [2] with a maximum duty ratio of 10%. Figure-1 shows the schematic configuration of the total radar and control system. Radar system consists of Exciter, receiver, and the out-door TR modules. Exciter generates (i) the pulse-coded 53-MHz waveform, which will be fed to the out-door TR modules via the RF distribution/combining network, and (ii) the 10-MHz clock/reference signal, which will be given to the back-end receive section and the direct digital receiver (DRx), and master timing and control signal generator (MTCSG) for their operation. The received RF signal is suitably amplified and band limited in the back-end receiver unit and fed to the DRx for processing and display. MTCSG generates the inter-pulse-period (IPP) marker trigger pulse, which will be used as reference to generate different timing and control signals. Timing signals are used to switch different RF switches in both transmit and receive paths where as the control signals are used to set the gain/attenuation, phase shift etc, in both transmit and receive paths. Master radar controller (RC) controls and monitors the functioning of all the radar subsystems.

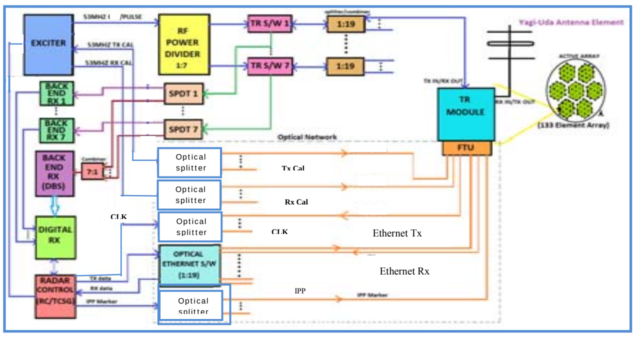

Figure-1: Block diagram of the control system for Pilot active phased array radar

Radar sub-systems need to be controlled properly for normal radar operation. Radar control system comprises of (i) the PC-based master RC with GUI interface, (ii) MTCSG, (iii) control and communication distribution network, and (iv) distributed timing signal generator (DTCSG) cards located in the out-door TR modules. RC is interfaced with other subsystems through Ethernet to communicate and control. Details of these functional blocks are presented below

Master Radar Controller (RC):

The PC-based RC performs the following basic functions. (i) Facilitates the user to set the experimental parameters and beams through GUI, (ii) stores the calibration phase-error data, generates phase correction file, and generates the phase data required for each TR module for the beams selected, (iii) pre-loads the experimental parameters and phase data into the MTCSG, Exciter, Receiver and TR modules through Ethernet switching network before starting the radar operation, and (iv) reads the status data from the TR modules during operation and displays the status data through the GUI. List of experimental parameters are shown in table-1.

Transmit pulse width (PW)	Exciter
Code flag	Exciter
Transmit/Receive (T/R) pulse	Exciter, Distr.network
IPP	MTCSG, TR Modules
Beams and their positions	TR modules
Blanking pulse	Back-end receiver
Receive attenuation	Back-end receiver
Band width	Back-end receiver
Coherent integrations (NCI)	DRx
FFT points	DRx
Incoherent integrations (NICI)	DRx
Start range window	DRx
Stop range window	DRx
Range bins	DRx
Experimental mode	DRx
Cycles	MTCSG, DRx, TRMs

RC is interfaced with other subsystems through Ethernet to communicate and control. Electrical Ethernet is employed to communicate with in-door subsystems such as Exciter, MTCSG, and DRx, where as the optical Ethernet is employed to communicate with and control the out-door TR modules. Figure-2 shows the sample GUI displays for setting the experimental parameters, running the operations and monitoring.

Master Timing and Control Signal Generator (MTCSG):

MTCSG works directly under the control of RC and interfaced through Ethernet. It receives the 10-MHz reference clock from the Exciter and generates the reference IPP marker when radar operation is started in the RC. It also generates the timing and control signals required for other subsystems such as Exciter, distribution network, TR modules, receive back-end, and DRx. MTCSG is an FPGA-based card and its photograph is shown in figure-3. All the timing pulses will be generated with reference to the IPP and the rising edge and width of these timing signals will be as specified in the experimental parameters in the RC GUI.

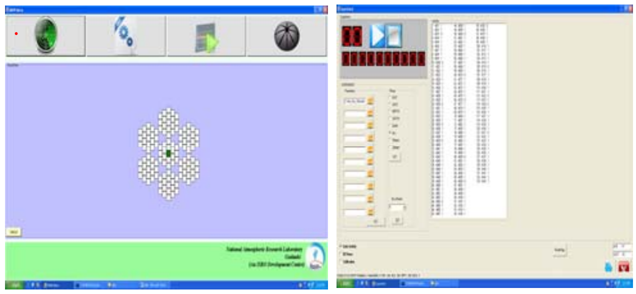

Figure-2: sample GUI of the radar controller

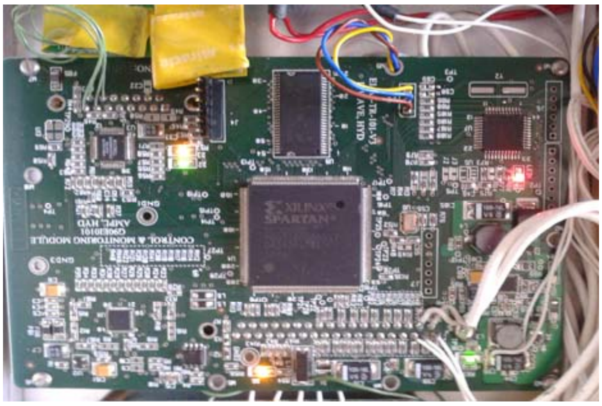

Figure 3: Photograph of the MTCSG card

Optical Distribution Network:

Since the out-door TR modules and the RC are separated by 140 m, communication and control of TR modules is carried out through Optical distribution network (ODN) is employed to interface the 133 TR modules with RC and MTCSG. ODN consists of (i) optical Ethernet communication switching network, (ii) signal distribution network, and (iii) multi-core optical fibers. Each TR module needs to communicate with the RC through Ethernet. Each TR module needs 16-MHz CLK and IPP trigger pulse from the MTCSG. The distribution scheme and photograph of a section is shown in the figure-4. Optical fibers are used to carry the Ethernet-Tx, Ethernet-Rx, IPP and CLK signals from the in-door RC/MTCSG to out-door TR modules. Optical fibers are also used to carry two additional RF signals, Cal-Tx and Cal-Rx, between the radar receiver and TR modules.

TR modules of each 19-element sub-group are connected to one 24-port Giga bit Ethernet switch. Seven such switches are used to communicate with the 133 TR modules as shown in figure-5. Signal distribution network distributes the centrally (instrumentation room) generated

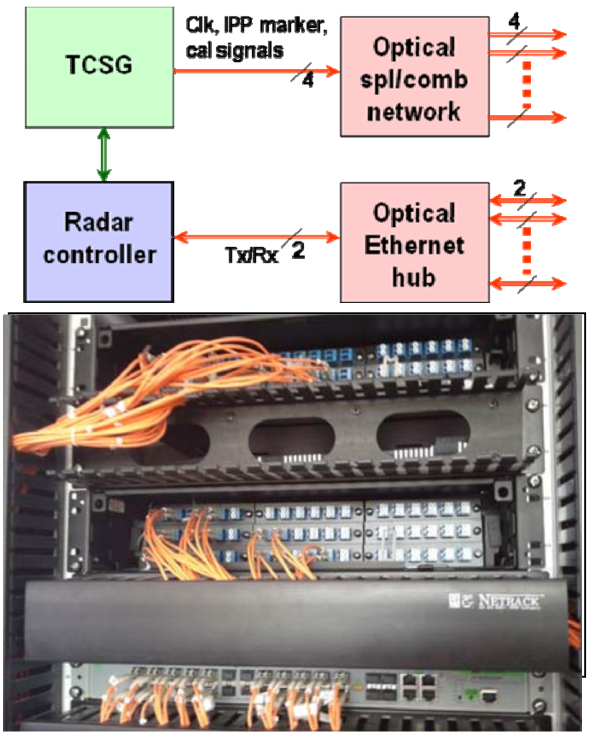

Figure 4: Optical distribution for timing, control and communication signals and photograph of one section

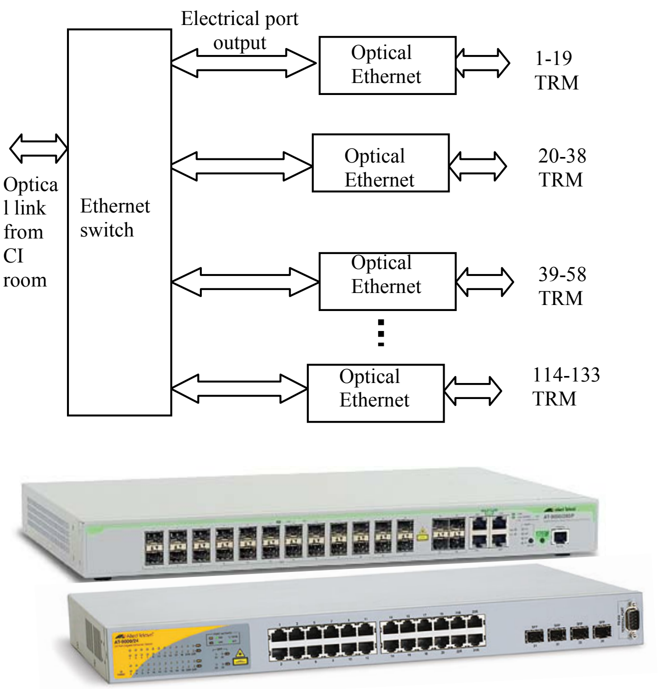

Figure-5: Block diagram of Etherenet distribution and Pictures of optical and electrical Ethernet switch.

IPP and CLK signals to all the TR modules in the antenna field. Distribution is carried out in two-levels; (i) one centralized 7-way distribution as shown in figure-6 and (ii) seven numbers of sub-array level (19-way) distribution as shown in figure-7. The IPP and 16-MHz CLK signal gene-

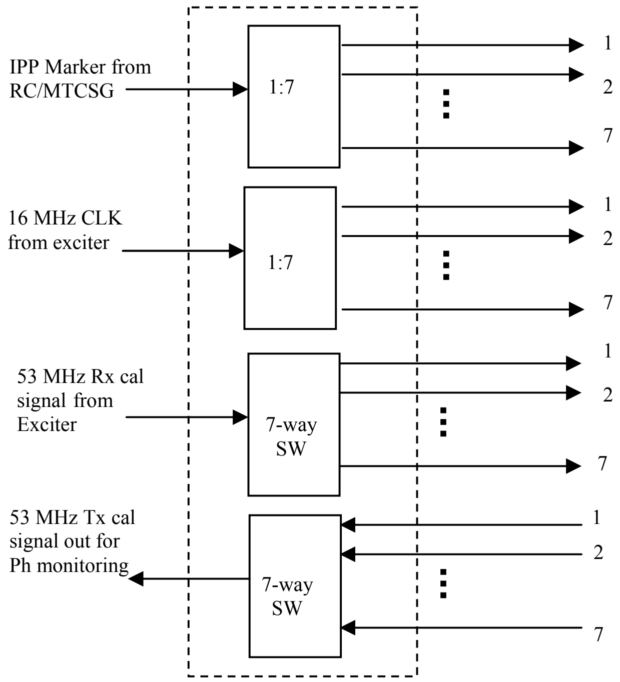

Figure-6: Block diagram of centralised optical distribution and calibration switching network

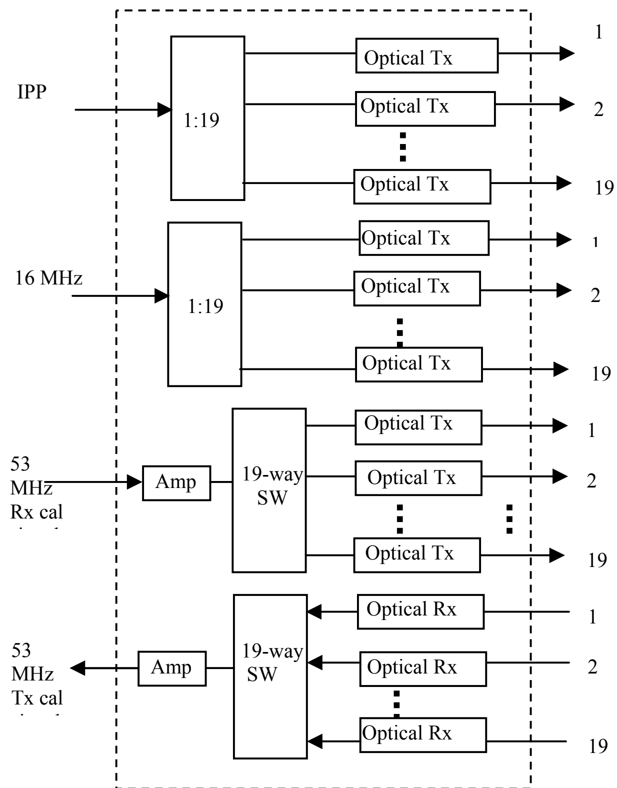

Figure-7: Block diagram of sub-array level optical distribution and calibration switching network

-rated by the MTCSG are first distributed in the electric domain and then converted into optical signals using optical transmitters. These optical signals are routed to the respective TR modules through Fiber Optic cable.

Distributed Timing signal control generator (DTCSG):

Each of the 133 TR modules in the out-door field consists of a Xilinx Spartan-3E based DTCSG card for control, communication and monitoring purposes. Figure-8 shows the block diagram and photograph of the DTCSG card, which basically contains the main control unit (MCU) and fiber transceiver unit (FTU). FTU translates the incoming optical domain (Ethernet Tx, Ethernet Rx, IPP, and CLK) signals into electrical domain using optical receivers. MCU is the CPU for the system with FPGA, micro controller, DDR, ADCs and other circuitry for monitoring and controlling. RC pre-loads the user specified experimental parameters in to the TR modules. Depending on the data received from the RC, MCU generates all the timing and control signals to different switches, 6-bit phase shifter, and 5-bit attenuator of the TR module in synchronization with IPP received from MTCSG. Phase and amplitude data are set as per the beam steering sequence preloaded by RC. Phase shift data is provided by RC. Interlocks are generated for excess input RF drive, excess junction temperature of the device failure, excess duty ratio, excess VSWR.

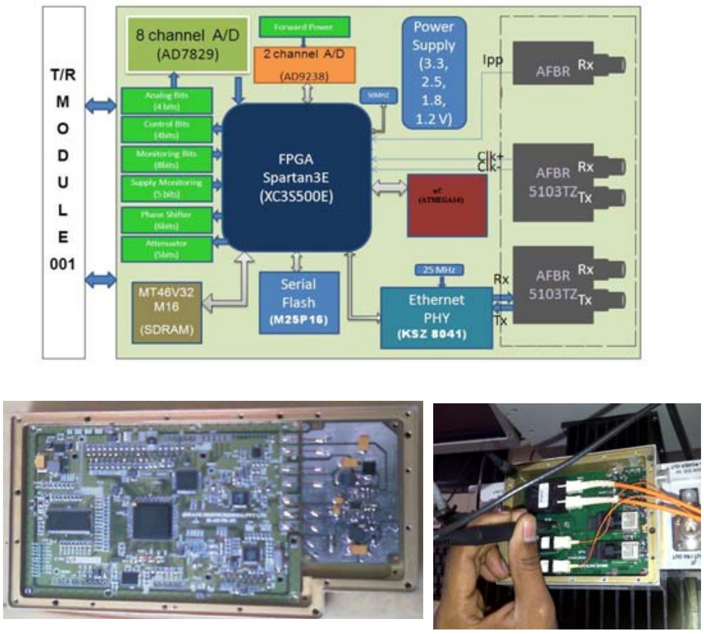

Figure-8 : Block diagram and photograph of the TSG card along with fiber transceiver unit.

Optical cable routing:

There are two types of cables used for optical fiber communication. A single TR module requires six cores to accommodate the Clock, IPP, Tx data, Rx data, Cal-Tx and cal-Rx signals. Hence a sub array consist of 19 TR modules requires 114 fiber optic cores. Multimode outdoor armored optical fiber of 62.5 / 125 micron which support 850 and 1310 nm is used. Figure-9 shows the 6-core optical fiber interface for one TR module.

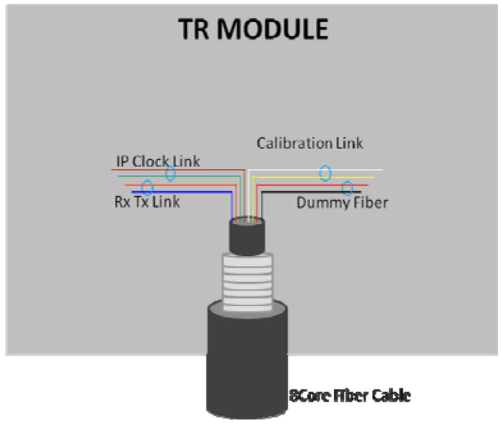

Figure 9: multi mode multi-core optical fiber cable

Phase calibration for TR modules:

Accurate phase monitoring of the TR modules is very crucial for normal operation of any phased array radar. Differential phase errors (resulting over the time) of the TR modules (both in Tx and Rx) must be measured and corrected from time to time for proper beam formation. Figure-10 shows the schematic within the TR module to monitor the phase in both Tx and Rx paths.

During the Tx mode, The Tx-RF signal at forward coupled port of the directional directional coupler is converted in to an optical signal by using optical transmitter. This signal is sent to the control room through the optical fiber network and converted back to the RF signal by using optical receiver. The TR module will be selected using the RF switching network in the instrumentation room. The phase of this signal is measured with the reference to the Tx pulse at the exciter.

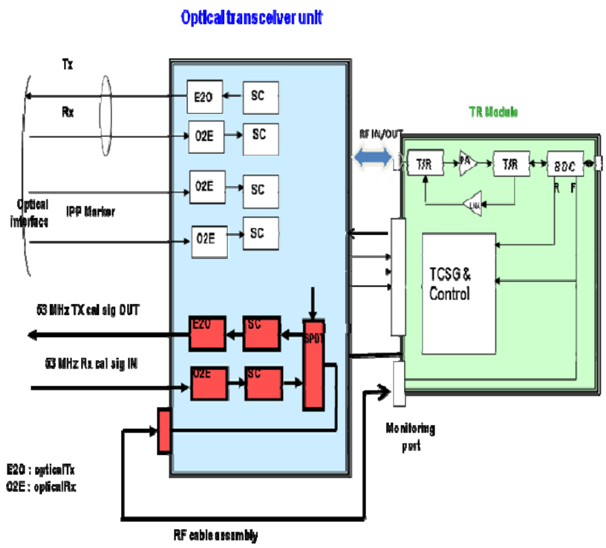

Figure-10 : Block diagram of the TSG card along with fiber transceiver unit.

In the receive mode a range-shifted simulated pulse from Exciter unit is routed to an RF switching network, converted into optical domain by optical transmitter, routed to the selected TR module. This signal is converted back to the RF signal by using optical receiver located in FTU and fed to the receive section of the TR module through bi-directional coupler. The signal then passes through the entire radar receive path. The phase of this signal is measured with reference to the simulated pulse.

Once the phases of all the TR modules are measured, RC computes the differential phase-errors and prepare the fresh phase correction file.

III CONCLUSION

Pilot active phased array radar system has been designed, developed and tested at NARL. This radar demonstrates the intended technology concepts like out-door installation of TR modules, beam steering, optical Ethernet-working, automatic Optical phase calibration. Preliminary comparison, made with other collocated instruments, found to be satisfactory. This radar system has survived unprecedented heavy lightning/ severe thunderstorms (occurred at NARL) without any problems owing to the optical fiber network adopted between the in-door RC PC and the out-door TR modules for control, communication and monitoring.

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